Analyses of the Seismic Characteristics of U.S. and Russian Cavity Decoupled Explosions

J. R. Murphy, I. O. Kitov*, N. Rimer, D. D. Sultanov*,
B. W. Barker and J. L. Stevens

Maxwell Laboratories, Inc.,S-CUBED Division
11800 Sunrise Valley Dr., Suite 1212
Reston, Virginia 22091
Contract No. F19628-93-C-0126
Sponsored by Phillips Laboratory

Abstract

The cavity decoupling evasion scenario remains as the greatest challenge to effective seismic monitoring of any eventual CTBT. However, despite the fact that the feasibility of this evasion concept was experimentally established nearly 30 years ago by the U.S. STERLING test, a number of issues of importance with respect to seismic monitoring still remain unresolved. In an attempt to address some of these issues, we have been working with scientists from the Russian Institute For Dynamics of the Geospheres to integrate the limited U.S. and Russian data and modeling experience into a uniform database on cavity decoupling. During the past year, our research has centered on analyses of data recorded from an extensive series of Russian HE cavity decoupling tests conducted in Kirghizia in 1960 and on analyses of seismic data recorded from six Russian nuclear tests conducted in a water-filled cavity at Azgir.

The Kirghizia HE cavity decoupling series consisted of 10 tamped and 12 cavity tests in limestone, and included tests of the same yield in both spherical and nonspherical cavities of equal volume. Comparisons of near-field seismic data recorded from these tests indicate that the low frequency decoupling effectiveness is approximately independent of cavity shape for roughly cylindrical cavities with length to width ratios of 6 or more, in agreement with previous theoretical simulation results. Spectral analyses of waveform data recorded at the same distances from 1.0 ton tamped explosions and from a 1.0 ton decoupled test in a spherical cavity with a radius of 2.88 m indicate a maximum low frequency decoupling factor of about 25 for this test. Theoretical simulations conducted using a limestone model which is consistent with these observed seismic data predict a corresponding nuclear decoupling factor of about 60 for this yield/volume ratio.

During the period 1975 to 1979, the Russians conducted a series of nuclear tests at Azgir in the water-filled, approximately 30 m radius cavity created by the 27 kt tamped explosion of 7/01/68. Six nuclear explosions with yields ranging from 0.01 to 0.50 kt were subsequently detonated in this cavity and seismic data were recorded from these tests at fixed stations in the range from about 1 to 75 km. Spectral analyses of the seismic data recorded from these tests at near-field stations reveal a consistent and pronounced yield dependence to the cavity/tamped source spectral ratios. Detailed theoretical simulations of these spectral ratio data are currently being conducted in an attempt to develop improved equations of state for salt for use in theoretical simulations of various cavity decoupling evasion scenarios.

Key Words: Seismic, Cavity Decoupling, Kirghizia, Azgir

* Institute For Dynamics of the Geospheres, Russian Academy of Sciences

Objective

It has long been recognized that the most effective means for evading the detection of a clandestine underground nuclear test is to detonate the explosion in a cavity which is large enough to substantially decouple the radiated seismic signal. In this project we are working with scientists from the Russian Institute for Dynamics of the Geospheres (IDG) to integrate the U.S. and Russian data and modeling experience into a uniform database on cavity decoupling. The objective of the study program is to validate a quantitative prediction capability which can be used by the seismic verification community to evaluate the plausibility of various cavity decoupling evasion scenarios.

Research Accomplishments

During the past year, our research has continued to focus on analyses of data recorded from an extensive series of Russian HE decoupling tests and on analyses of seismic data recorded from six Russian nuclear tests conducted in a water-filled cavity at Azgir (Murphy et al., 1994). The HE decoupling tests consisted of a series of 22 tamped and cavity explosions conducted in a mine in the Tywya Mountains of Kirghizia in the summer of 1960. The tests were conducted in hard, homogeneous limestone in chambers excavated from alcoves constructed off the sides of the main access tunnel to the mine. The decoupled tests were conducted in spherical cavities having diameters ranging from about 3.5 to 10 m, as well as in nonspherical cavities with volumes of about $25m^3$. The test series was composed of 10 tamped and 12 decoupled explosions having yields of 0.1, 1.0 and 6.0 tons. The explosives consisted of ammonium nitrate, except for the two 6.0 ton tests which utilized a mix of TNT and ammonium nitrate. For the cavity tests, the explosives were suspended in the chambers and included cases in which the explosives were positioned off-center, near the cavity walls. The configurations of the various cavity tests are graphically summarized for each of the five test chambers in Figure 1.

Seismic data were recorded from these tests at locations in the mine over a distance range extending from about 10 to 250 m from the sources. Peak amplitudes of displacement and velocity have been reported for over 250 of these recording locations and about 60 of the corresponding seismograms have been digitized at IDG and prepared for detailed spectral analysis. Direct comparisons of the peak displacements recorded from cavity tests of the same yield provide good indications of the relative low frequency decoupling efficiencies of different cavity configurations. For example, Figure 2 shows comparisons of the peak displacement data observed from 0.1 ton decoupled tests in spherical and elongated cavities of the same volume (i.e. $25m^3$). The leftmost display in this

figure corresponds to a cylindrical cavity with length to width (L/W) ratio of about 3, while the other two displays are for tests in a nonsymmetrical cavity with dimensions of about 1m X 2m X 12m (i.e., L/W ≈ 6-12), one with the charge at the center (middle) and one with the charge near the end of the chamber (right). It can be seen that the peak displacement data observed from these various cavity configurations are all quite comparable, which suggests that the low frequency decoupling effectiveness is not very sensitive to cavity shape at this yield/volume ratio. The only notable anomaly in Figure 2 is for the case of the nonsymmetrical cavity with the charge at the end, for which the close-in displacement levels are somewhat higher than those observed from the spherical cavity of the same volume. However, this offset is fairly small and is not evident at distances which are large with respect to the cavity dimensions. This observed insensitivity to cavity shape is consistent with the theoretical simulation results previously reported by Stevens et al. (1991).

In order to make a fully quantitative assessment of decoupling effectiveness, it is necessary to carry out detailed spectral analyses of the complete waveform data. Such an analysis has been carried out using data recorded from the 1.0 ton decoupled test in the 2.88 m radius spherical cavity and the resulting estimated decoupling factor is shown as a function of frequency in Figure 3. It can be seen that these data indicate that a maximum low frequency decoupling factor of about 25 was achieved in this test. Also shown on this figure are the theoretical decoupling factors predicted for 1 ton HE and nuclear explosions in a 2.88 m radius cavity in limestone using our nonlinear finite difference code. It can be seen that although there are still some unexplained discrepancies in spectral shape over this band, the theoretical HE simulation does provide a fairly good description of the observed low frequency decoupling factor in this case. As has been noted previously by Glenn and Goldstein (1994) and others, the corresponding theoretical nuclear decoupling factor for this yield/volume ratio is predicted to be significantly larger, with a maximum low frequency value of about 60, roughly consistent with the value of 70 observed from the STERLING nuclear cavity test in salt.

During the period 1975 to 1979, the Russians conducted a series of nuclear tests at Azgir in the water-filled cavity created by the 27 kt tamped explosion of 7/01/68. The tamped explosion was detonated at a depth of 597 m and produced a nearly spherical cavity with a volume equal to that of a spherical cavity with a radius of 28.9 m. Six nuclear explosions with yields ranging from 0.01 to 0.50 kt were subsequently detonated in this cavity and seismic data were recorded from these tests at fixed stations in the range from about 1 to 75 km. Although these tests were not decoupled and, in fact, showed enhanced coupling in some frequency bands, their wide range in energy release at a fixed detonation point provides a unique opportunity to further investigate the seismic source characteristics of explosions in salt. Seismic data recorded from the tamped test which created the cavity, and from four of the water-filled cavity tests (i.e., 0.01,

0.08, 0.10 and 0.35 kt) have been digitized at IDG and subjected to detailed spectral analysis. Displacement spectra computed from the vertical component signals recorded from the tamped and four cavity tests at the station located at a range of 1.17 km are shown in Figure 4. Note that because of the dynamic range limitations of the hand-digitized data, the spectrum for the tamped 27 kt explosion, which is associated with a much lower corner frequency than those of the cavity tests, is only considered to be reliable below about 5 Hz, while the cavity test spectra are estimated out to 20 Hz. Assuming that propagation path effects on the spectra are of second order importance at these near-source distances, the observed tamped spectra were cube-root scaled to the yields of the cavity tests and cavity/tamped spectral ratios were computed using the data from stations at 1.17, 1.71 and 7.8 km. The resulting spectral ratios for a given explosion were found to be quite consistent at these three distances, suggesting that they represent useful approximations to the corresponding source spectral ratios. Consequently, the three spectral ratios for each cavity test were logarithmically averaged and the resulting estimates of the cavity/tamped source spectral ratios for the four cavity tests are shown in Figure 5. It can be concluded from this figure that the 0.35 kt water-filled cavity test shows enhanced low frequency coupling with respect to that expected from a tamped explosion of the same yield in salt, while the 0.10 kt and 0.08 kt cavity test sources appear to be very similar to those expected for tamped tests of comparable yield. The lowest yield 0.01 kt cavity test source, on the other hand, shows a pronounced resonance in the band around 10 Hz, where the overshoot of the low frequency level reaches a factor of 5 or more. Nonlinear finite difference simulations of this test indicate that this resonance is associated with reverberation of the explosive shock wave in the water-filled cavity. Detailed theoretical simulations of all these spectral ratio data are currently being conducted in an attempt to infer an improved equation of state for salt for use in the modeling of various cavity decoupling evasion scenarios.

Conclusions and Recommendations

Over the past several years, we have been working with scientists from the Russian Institute For Dynamics of the Geospheres (IDG) in an attempt to integrate the available U.S. and Russian data and modeling experience on cavity decoupling. Current research activities have been focusing on the analysis of data recorded from an extensive series of Russian HE decoupling tests and on an analysis of seismic data recorded from a series of nuclear tests conducted in a water-filled cavity in salt at Azgir. Comparisons of near-field seismic data recorded from the Kirghizia HE decoupling tests have indicated that the low frequency decoupling effectiveness is approximately independent of cavity shape for roughly cylindrical cavities with length to width ratios of 6 or more.

Furthermore, detailed spectral analyses of Kirghizia waveform data recorded from 1.0 ton HE tests indicate a maximum low frequency decoupling factor of about 25, and theoretical simulations suggest that this corresponds to a nuclear decoupling factor of about 60 for this yield/cavity volume ratio in limestone. Seismic data recorded from the Azgir water-filled cavity tests have been analyzed and a pronounced yield dependence has been identified in the resulting cavity/tamped source spectral ratios. Although these cavity tests were not decoupled and, in fact, show enhanced coupling in some frequency bands, their wide range in energy release at a common detonation point is providing a unique opportunity to further quantify the seismic source characteristics of explosions in salt.

References

Glenn, L. A. and P. Goldstein (1994), "Seismic Decoupling with Chemical and Nuclear Explosions in Salt," Journal of Geophysical Research, Vol. 99, No. B6, p. 11,723.

Murphy, J. R., I. O. Kitov, J. L. Stevens, D. D. Sultanov, B. W. Barker, N. Rimer and M. C. Friedman (1994), "Analyses of the Seismic Characteristics of U.S. and Russian Cavity Decoupled Explosions," S-CUBED Technical Report PL-TR-94-2295, ADA292881

Stevens, J. L., N. Rimer, J. R. Murphy and T. G. Barker (1991), "Simulation of Seismic Signals From Partially Coupled Nuclear Explosions in Spherical and Ellipsoidal Cavities," S-CUBED Technical Report SSS-FR-91-12735.

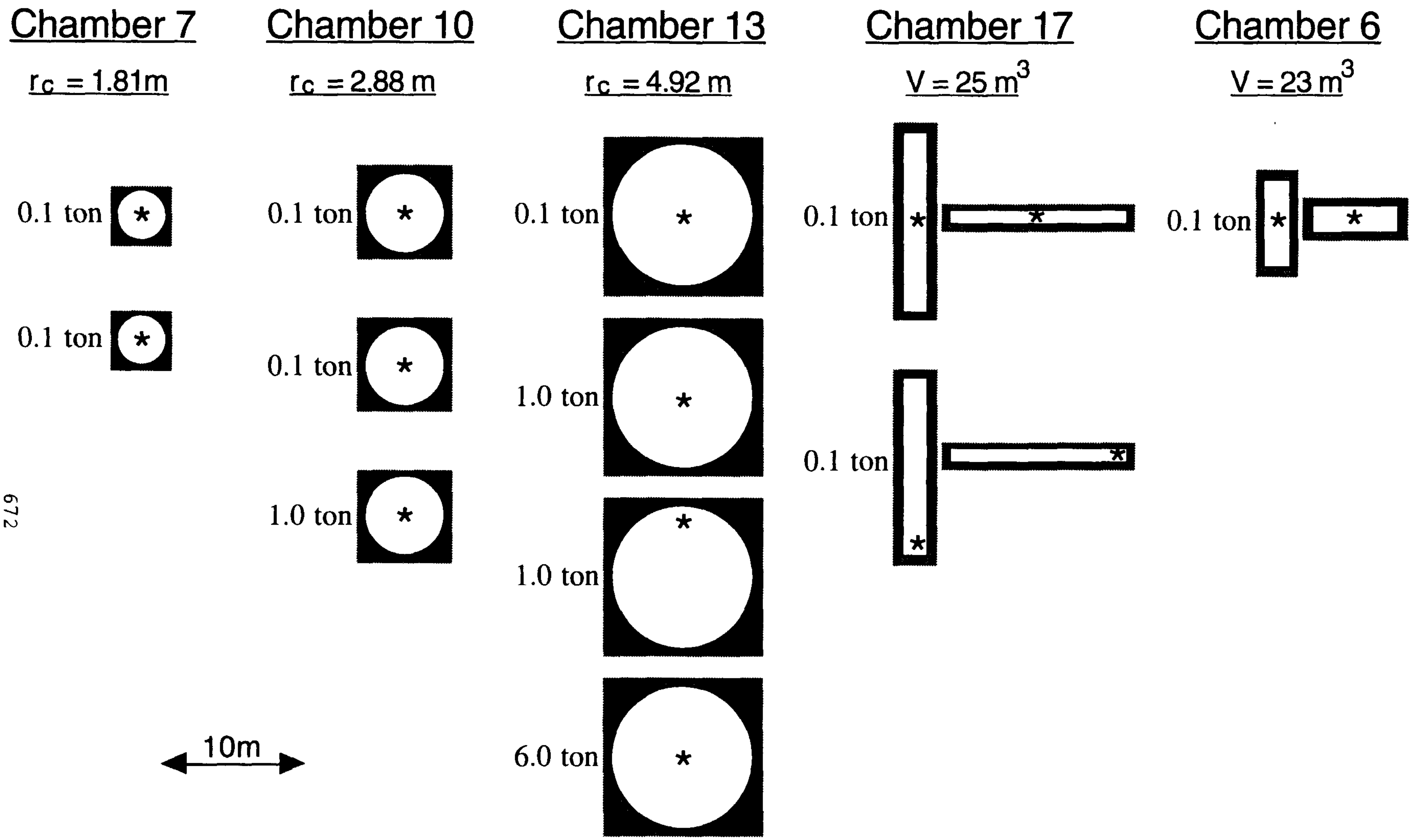

Figure 1. Graphical summary of the Kirghizia HE decoupling tests conducted in each of the excavated explosion chambers. The asterisk denotes the emplacement location of the charge within the chamber for each test. For the nonspherical cases, both horizontal (left) and vertical (right) sections through the chambers are displayed.

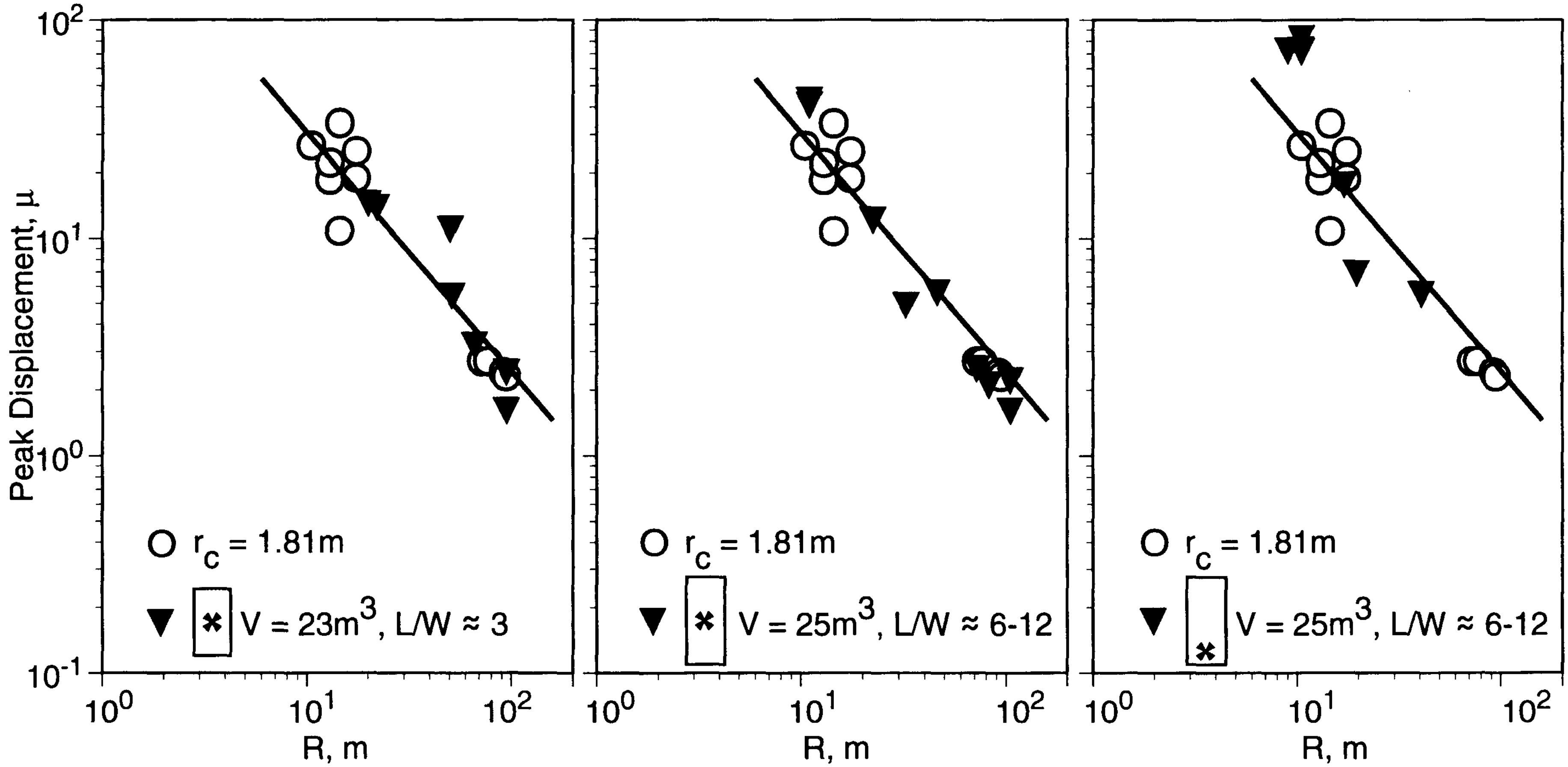

Figure 2. Comparison of peak displacement data observed from Kirghizia 0.1 ton decoupled tests in spherical and elongated cavities of comparable volume. For the nonspherical cavities, the asterisks denote the charge location.

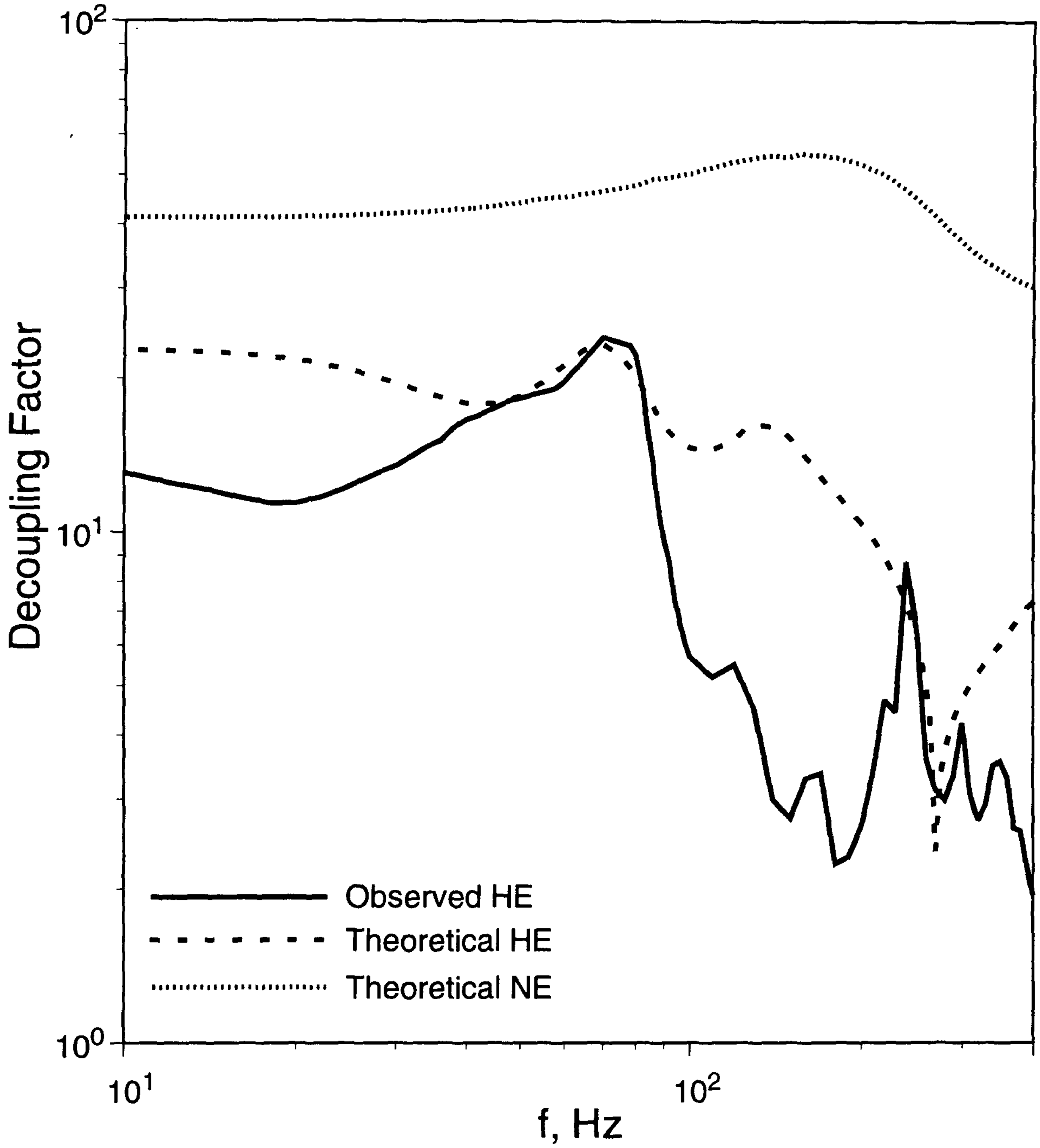

Figure 3. Comparison of observed and theoretical frequency dependent decoupling factors for 1 ton explosions in a 2.88m radius spherical cavity in Kirghizia limestone.

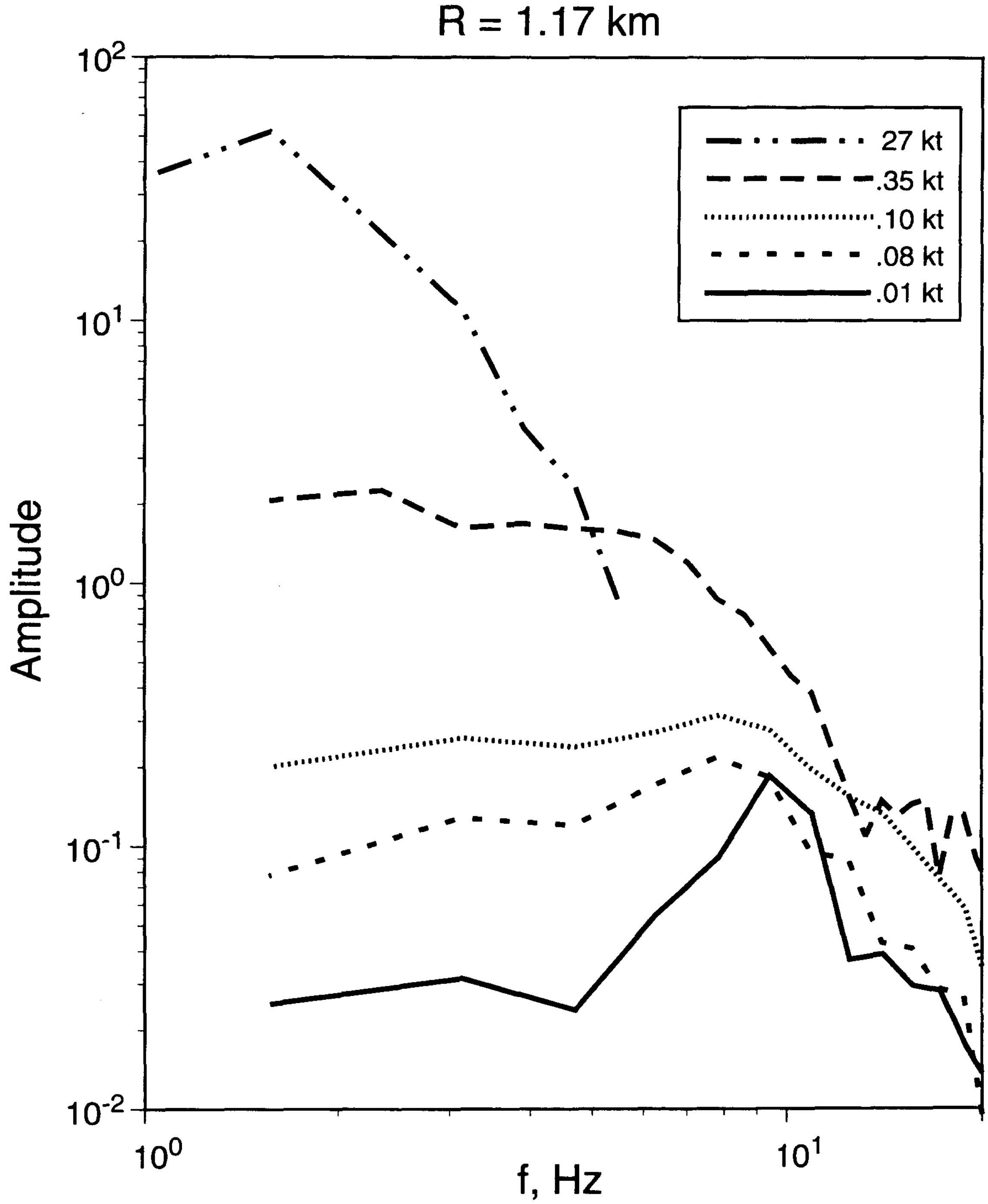

Figure 4. Comparison of displacement spectra computed from vertical component data recorded from the Azgir tamped and water-filled cavity tests at a range of 1.17 km.

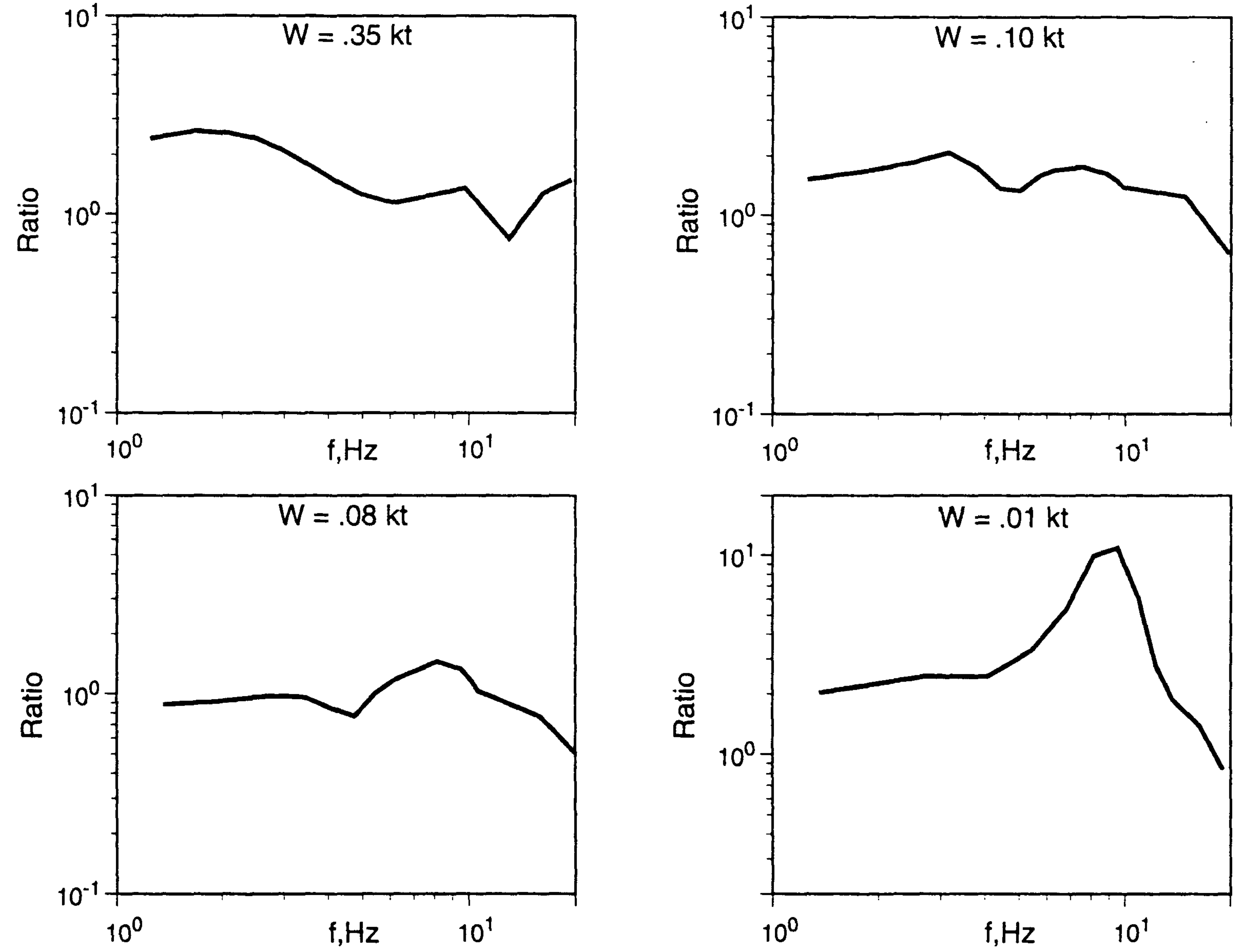

Figure 5. Average cavity/tamped source spectral ratios estimated from seismic data recorded from the Azgir tamped and selected water-filled cavity tests.